Mechanisms of Fluid-Mud Interactions Under Waves

Robert A. Dalrymple, John H. Trowbridge, Dick K.P. Yue , Samuel J. Bentley, Gail C. Kineke,
Yuming Liu, Chiang C. Mei, Lian Shen, Peter A. Traykovski,
c/o Dept of Civil Engineering
The Johns Hopkins University
3400 North Charles Street
Baltimore, MD 21218
phone: (410) 516-7923 fax: (410) 516-7473 email: rad@jhu.edu

Award Number: N00014-06-1-0718
http://www.ce.jhu.edu/dalrymple/MURI

LONG-TERM GOALS

The goals of this project are to investigate the mechanisms for wave dissipation in the presence of bottom mud. There are a variety of possible mechanism for the decay of wave energy as waves propagate over muds; however, they have not all been validated in the field nor quantified in terms of their relative importance and damping rates in the field or the laboratory. Implementation of the mechanisms into numerical models will provide the ability to infer from the sea surface the nature of the bottom material.

OBJECTIVES

We will measure wave damping due to mud off the coast of Louisiana, quantifying the dynamics of the bottom mechanisms responsible for the dissipation of wave energy. We will examine different mechanisms for the damping of wave energy by bottom mud in the laboratory and through the use of theoretical and numerical models. These damping mechanisms include the direct forcing of the mud by the wave-induced bottom pressure and velocities; indirect forcing through nonlinear surface wave effects (including wave groups); resonant forcing of interfacial waves at the water/mud interface; damping and shear instabilities in the lutocline; and large scale broadband mechanisms that involve a complex sea state and a combination of the above mechanisms.

APPROACH

The approach is three-pronged: a field effort will involve experiments within a mud patch offshore the coast of Louisiana; a laboratory effort, involving examining the above mechanisms in a controlled environment; and a theoretical and numerical approach, with the ultimate objective of providing numerical models that include wave damping over mud.

The field work will consist of three field campaigns (2007 pilot study; 2008 main field experiment, 2010 optional experiment) of wave and bottom measurements. The experiments involve the use of a bottom mounted quadrapod (see figure) that has an array of vertically oriented pulse-coherent pencil-beam Doppler sonars to measure the horizontal and vertical structure of the velocity and concentration of sediment at the bottom. In addition, a surface buoy will provide atmospheric measurements, and two tripods at the seaward and landward ends of the experimental area will have acoustic Doppler current

Report Documentation Page

Form Approved
OMB No. 0704-0188

Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.

1. REPORT DATE **2006**	2. REPORT TYPE	3. DATES COVERED **00-00-2006 to 00-00-2006**

4. TITLE AND SUBTITLE **Mechanisms of Fluid-Mud Interactions Under Waves**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **The Johns Hopkins University,Dept of Civil Engineering,3400 North Charles Street,Baltimore,MD,21218**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

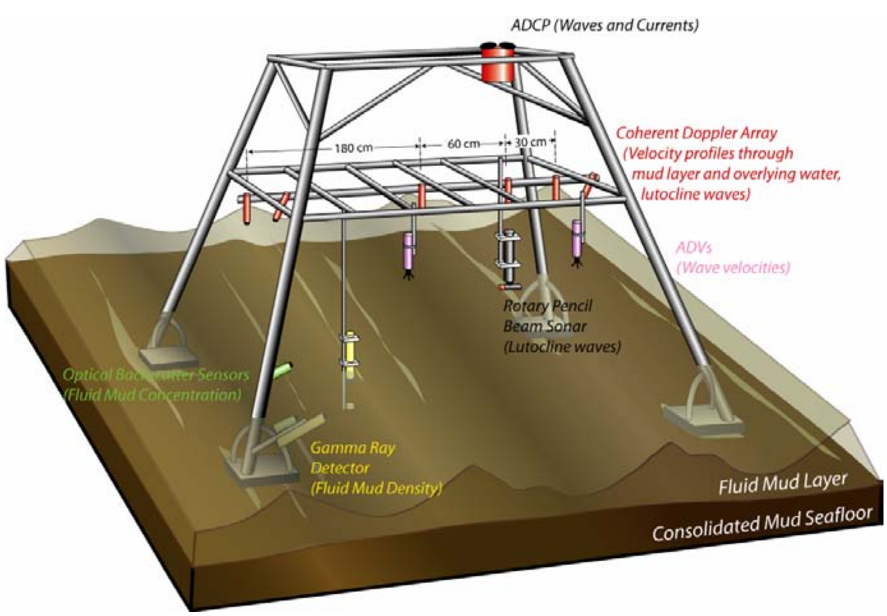
15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**4**	

profilers with waves enhancement to provide estimates of the directional wave spectrum and energy flux into the study area.   These tripods will also have acoustic backscatter devices to measure the thickness and mud layer concentrations. In addition, cores of the seabed will be taken to determine recent depositional history, porosity, and mixing depth.

WORK COMPLETED

Field: Preparation for the field experiments are underway. ADCP instruments ordered and shipboard mounting brackets under construction.



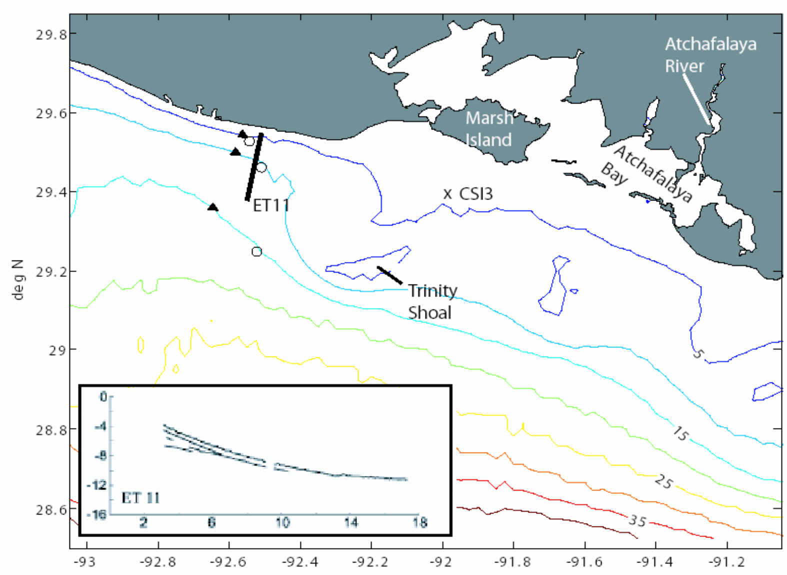
New sonars are being tested for use on the quadrapod to be deployed during the field experiment.

Theory and Modeling: A model for direct simulation of the waves and mud has been developed. A theory for non-Newtonian mud has been developed. Dissipation mechanisms for the SNOW wave model are being implemented.

Laboratory: Wavemakers in the wave tank at Johns Hopkins University have been made operational. The false bottom for the mud layer has been designed and is being constructed. Kaolinite mud has been received.

RESULTS

Field: At Boston College, Gail Kineke and Masters student Michelle Lermon inventoried bottom and suspended sediment samples from the proposed field site off the Chenier Plain coast, collected during a prior ONR project (1998-2001). Twenty samples from a likely deployment area were selected for grain size analysis to characterize variability in bottom sediment with different discharge and wave/current energy conditions. Analyses are in progress. Prior hydrographic/suspended sediment surveys were examined to



define an area likely to have the fluid mud conditions necessary for the pilot wave-attenuation experiment planned for Feb-Apr 2007. The prior data set was instrumental in planning discussions among the field team to choose a likely deployment line and outline an area for reconnaissance work to identify existing structures (rigs and platforms) for instrument deployment. Three internally-logging high concentration Optical Backscatter Sensors were ordered and will be calibrated in the lab with existing sediment samples from the field area prior to the February deployment.

At WHOI, we have been working on interfacing an Imagenex delta-T multibeam sonar with a pc-104 data acquisition system to image small scale wave and instabilities on the mud water interface.

We are also working on a new generation of pulse coherent Doppler sonar based on a WHOI low power Doppler board design. This will be one of the first pulse coherent profiling sonars with low enough power consumption for practical autonomous use. Both of these systems will be used in both the MURI project and the MVCO Ripples DRI.

Omni Technologies of New Orleans is fabricating a new submarine gamma densitometer for measurement of high-concentration sediment suspensions in upcoming field experiments on the Louisiana coast. The design for the instrument was developed by Sam Bentley (Memorial University) and Sean Griffin (Omni Technologies). In preparation for the field experiment, reconnaissance surveys of the field area are scheduled for November 2006, to identify structures (oil production and well platforms) suitable for tethering seabed instrument systems between the 15 m and 2 m isobaths.

Analysis and Modeling: This past summer a undergraduate student fellow from John Hopkins went to WHOI and worked on re-examining Lousiana shelf wave data that had been collect by G. Kineke and comparing the results to SWAN simulations. He found that the wave attenuation in periods with moderate waves and low wind was fairly well described with friction factors that are typical of rippled sandy sea floors. He also found that in periods with stronger winds the spectral energy balance was sensitive to both the wind input and the bottom friction, and that separating these contributions was difficult.

The numerical modeling research at JHU has been focused on developing numerical capabilities for the direct simulation of vortical and turbulent mud flows coupled with wave motions at small spatial scales. For this purpose, we have developed a direct simulation code for the unsteady three dimensional mud motion under the action of surface gravity waves. In our simulation, the continuity equation and momentum equations in the primitive form are simulated with a hybrid pseudo-spectral and finite-difference scheme. A clustered grid is used in the vertical direction to fully resolve the bottom boundary layer and the mud-water surface layer. An explicit Adam-Bashforth scheme of second-order accuracy in time integration is used for the viscous terms, of which the mud viscosity can be modeled as a constant, Bingham plastic with viscosity regularization, or a general Herschel-Bulkley fluid. The implementation of an implicit time integration scheme that allows larger time-step will be our immediate next step of code development. The code developed in this research has been parallelized using MPI and it has been tested and optimized on a number of high-performance parallel computing platforms including an IBM P4, a Dell Linux cluster, and a TeamHPC Beowulf cluster. With the development of this high-performance numerical tool, we are expecting to obtain a complete description of the mud motion at small scales, so that key transport and dissipation processes in the mud can be quantified and modeled. Our next step of research will be the direct, two-way coupling of

this viscous mud simulation with the potential flow based wave simulation using SNOW developed at MIT.

At MIT, the development of theoretical and computational models for the study of dissipation mechanisms of surface wave propagation over muddy bottom has begun.

Using theory, we have been investigating the mechanisms and characteristics of mud motion induced by regular water waves on a horizontal seabed. The mud is treated as a non-Newtonian fluid with a power-law relation between stress and strain. The rheological properties are estimated for prescribed concentration of cohesive sediments, according to known experiments. Based on the first-order theory of waves, we have derived the nonlinear governing equations of mud motion for the practical case where the mud depth is much smaller than both the water depth and wavelength. The mud motion of boundary layer type will be solved shortly by a semi-numerical method. The results will be used to calculate the energy dissipation rate and wave attenuation.

In numerical modeling, we have started the development of physics-based dissipation models associated with mud motion on sea bottom and the integration of these dissipation models into a phase-resolved wavefield evolution prediction tool. We have focused on the study of nonlinear interactions and dissipations of surface and interfacial waves of two-layer fluids with different densities. While this development has been ongoing, we have also been extending the large-scale phase-resolved wave prediction computations to include multi-layer flows and as well as broadband wavefields.

Laboratory –The wave tank at Johns Hopkins is being converted for the first set of experiments. The four hydraulically-actuated piston wavemakers are now operational under feedback control and with simultaneous data acquisition. A stainless steel frame for a Corian ramp from the wave paddles to the beginning of the 10 cm deep mud bed has been fabricated. The wave absorber system for the tank is under construction. Seven wireless wave gages are being integrated into the data acquisition system and the mounting brackets constructed.

Seven tons of Kaolinite clay has been received for creating the mud bed in the 2.5 m wide, 2 m deep, and 22 m long wave tank. The test section is to be 10 cm deep and 10 m long. We have enough clay for several reinstallations of the mud bed.

IMPACT/APPLICATIONS

The result of this combined field/laboratory/theory/modeling effort will be models for the propagation of water waves over regions of bottom mud. The dissipation due to a variety of mechanisms will be in the models; however, the most likely mechanisms will be determined from the field experiments. Laboratory experiments will provide data to elucidate the mechanisms of energy transfer from the waves to the sediment.